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SPE5 Sub-Scale Test Series Summary Report

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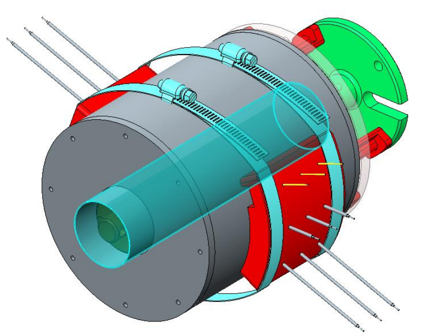
Executive Summary

A series of 2 SPE5 sub-scale tests were performed to experimentally confirm that a booster system designed and evaluated in prior tests would properly initiate the PBXN-110 case charge fill. To conduct the experiments, a canister was designed to contain the nominally 50 mm diameter booster tube with an outer fill of approximately 150 mm diameter by 150 mm in length. The canisters were filled with PBXN-110 at NAWS-China Lake and shipped back to LLNL for testing in the High Explosives Applications Facility (HEAF). Piezoelectric crystal pins were placed on the outside of the booster tube before filling, and a series of piezoelectric crystal pins along with Photonic Doppler Velocimetry (PDV) probes were placed on the outer surface of the canister to measure the relative timing and magnitude of the detonation. The 2 piezoelectric crystal pins integral to the booster design were also utilized along with a series of either piezoelectric crystal pins or piezoelectric polymer pads on the top of the canister or outside case that utilized direct contact, gaps, or different thicknesses of RTV cushions to obtain time of arrival data to evaluate the response in preparation for the large-scale SPE5 test. To further quantify the margin of the booster operation, the 1st test (SPE5SS1) was functioned with both detonators and the 2nd test (SPE5SS2) was functioned with only 1 detonator. A full detonation of the material was observed in both experiments as observed by the pin timing and PDV signals. The piezoelectric pads were found to provide a greater measured signal magnitude during the testing with an RTV layer present, and the improved response is due to the larger measurement surface area of the pad. This report will detail the experiment design, canister assembly for filling, final assembly, experiment firing, presentation of the diagnostic results, and a discussion of the results.

1. Experiment Design

The canister was designed to utilize the thin walled stainless steel booster tube inserted into a thin-walled aluminum canister with a removable cover. Aluminum was chosen due to the known compatibility with the PBXN-110 material and ease of fabrication in a short time period. Figure 1 shows a schematic of the initial design of the canister.



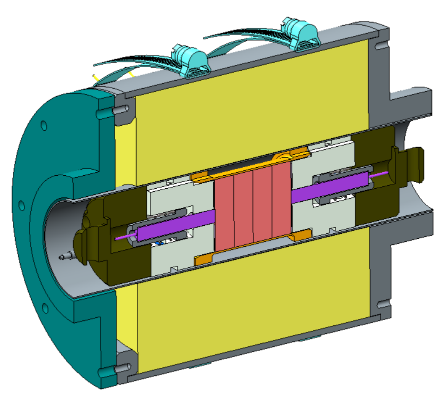


Figure 1. The initial design of the SPE5 sub-scale assembly shows the aluminum canister with end caps to facilitate the PBXN-110 fill while utilizing the booster tube for insertion of the booster assembly.

After the initial design, a new cover was designed and fabricated to allow the addition of 6 top pins to evaluate the response in advance of the SPE5 test. The pin and PDV locations on the outside of the case were also rotated slightly to accommodate all of the different diagnostics with minimal impact as a result of the axial symmetric nature of the experiment. The design is documented in drawing AAA15-504608-AA and shipping plates as AAA15-504609-AA.

2. Experiment Canister Assembly

The SPE5 sub-scale canisters were assembled using RTV 3110 with RTV-3010-S catalyst based on the known chemical compatibility with PBXN-110. Figure 2 details a set of step by step photographs with details in the figure caption. Figure 3 shows the completed assemblies ready for shipment to NAWS-China Lake for filling.

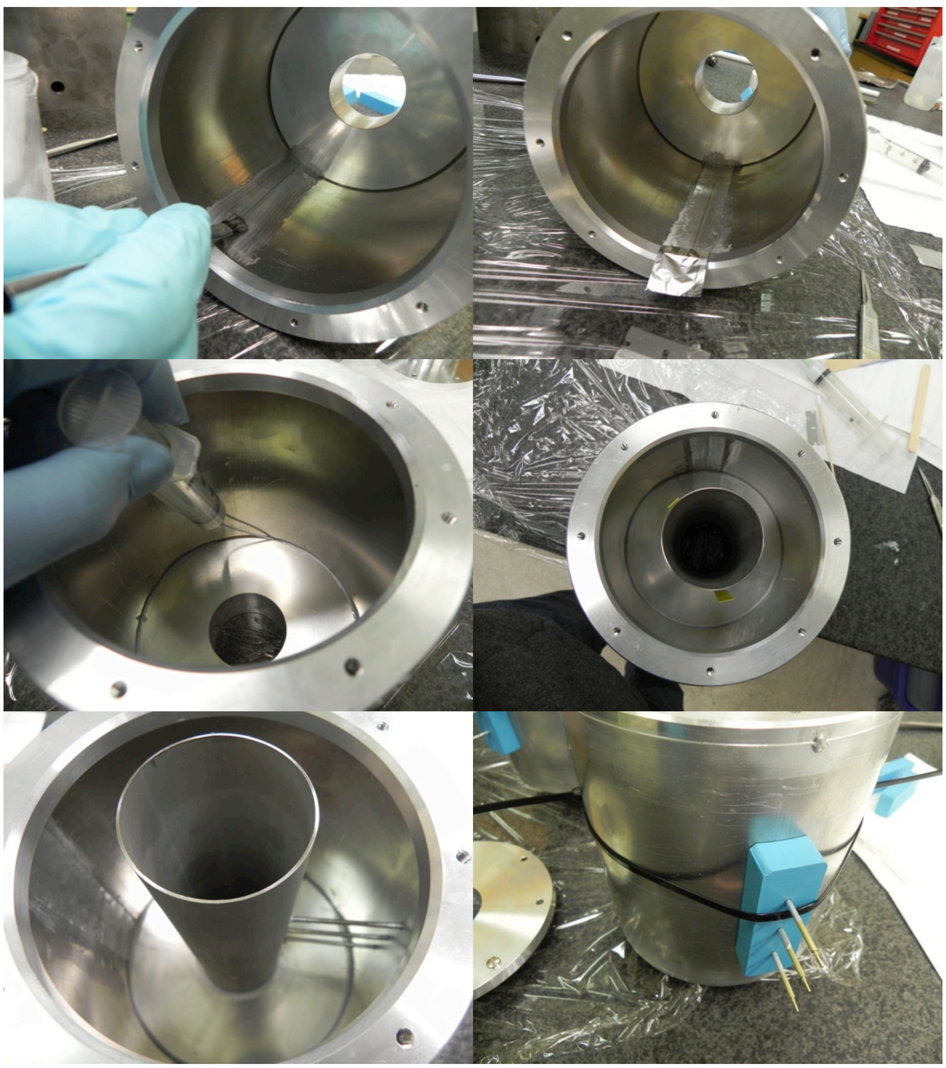


Figure 2. A series of photographs showing the preparation of the assembly canister showing application of the RTV along the weld seam (upper left), placement of an aluminum foil at the seam (upper right), placement of the RTV along the case seams (center left), placement of the

booster tube with alignment shims (center right), placement of the interior case pins in contact with the outside of the booster tube (lower left), and gluing of a plastic pin block on the outside for pin support (lower right).

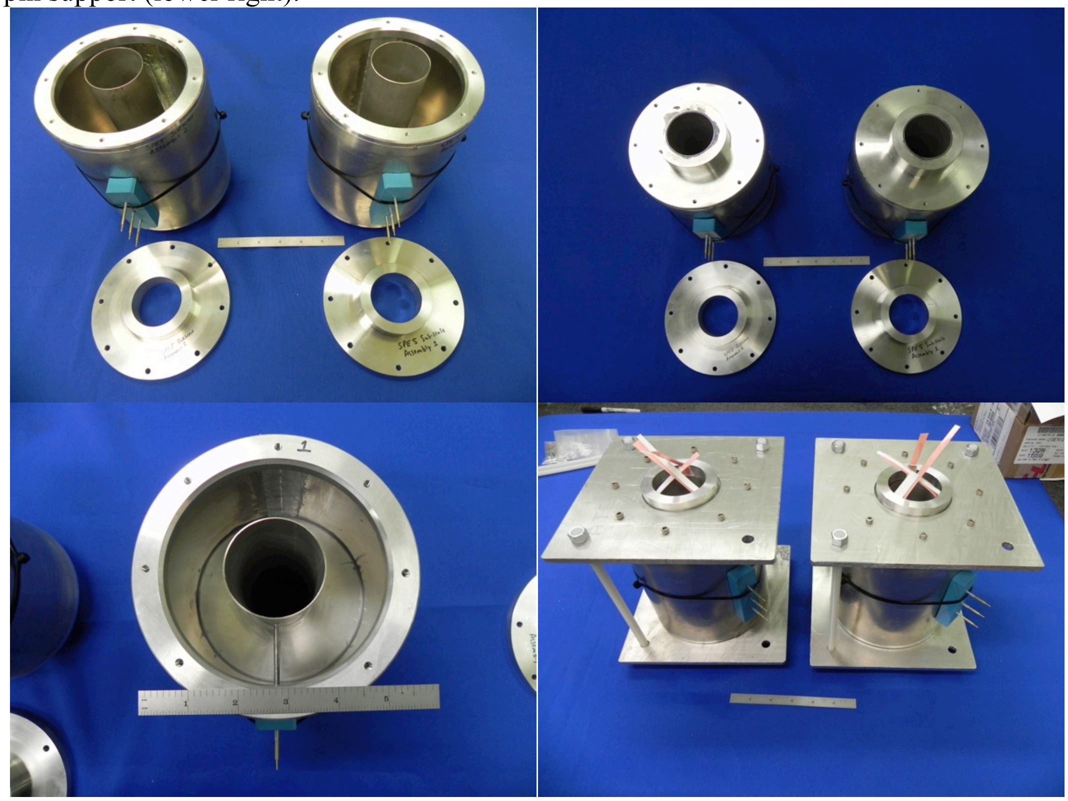


Figure 3. A series of photographs showing the top view (upper left), bottom view (upper right), interior view (lower left), and final assembly for shipping (lower right) of both of the SPE5 sub-scale experiment canisters.

3. PBXN-110 Explosive Fill, Shipping, and Radiography

The experiment canisters were shipped to NAWS-China Lake for filling with PBXN-110. Table 1 provides the pre-and-post-fill weights of the assemblies and this SPE5 Sub-scale explosive mix was formulated as mix #151203. After filling, the parts were shipped to Site 300 using an Interim Hazard Classification (IHC) for shipping. After being radiographed at Site 300 where no anomalies were observed, the articles were individually shipped to HEAF for testing.

Table 1. Measured weights of the SPE5 sub-scale containers before and after the PBXN-110 explosive fill.

LLNL SPE5 Subscale Test Canisters - PR11225

Energetic: PBXN-110 ***Mix Date:*** 12/02 - 12/03/2015
Engineer: Z. Goedert ***Cast Date:*** 12/03/2015

Asset Serial Number	SPE5 Assembly 1	SPE Assembly 2
Empty Pre-Cast Weight	1431.78 g	1434.07 g
With Mold Release	1432.63 g	1435.14 g
Post Cast Weight	5025.33 g	4958.39 g
Assembled Weight	15.35 lb	15.30 lb
Explosive Weight	3592.70 g	3523.25 g

4. SPE5 Sub-Scale Test 1 (Article 2)

Each assembly started with assembling a booster using the established Initiator Assembly Procedure (SPE050303-009PRC). Figure 4 shows a series of photographs with captions highlighting the assembly. Figure 5 shows a photograph of the completed booster assembly. Once the booster assembly was complete, the top pin plate was installed followed by the placement of external pins and PDV probes.

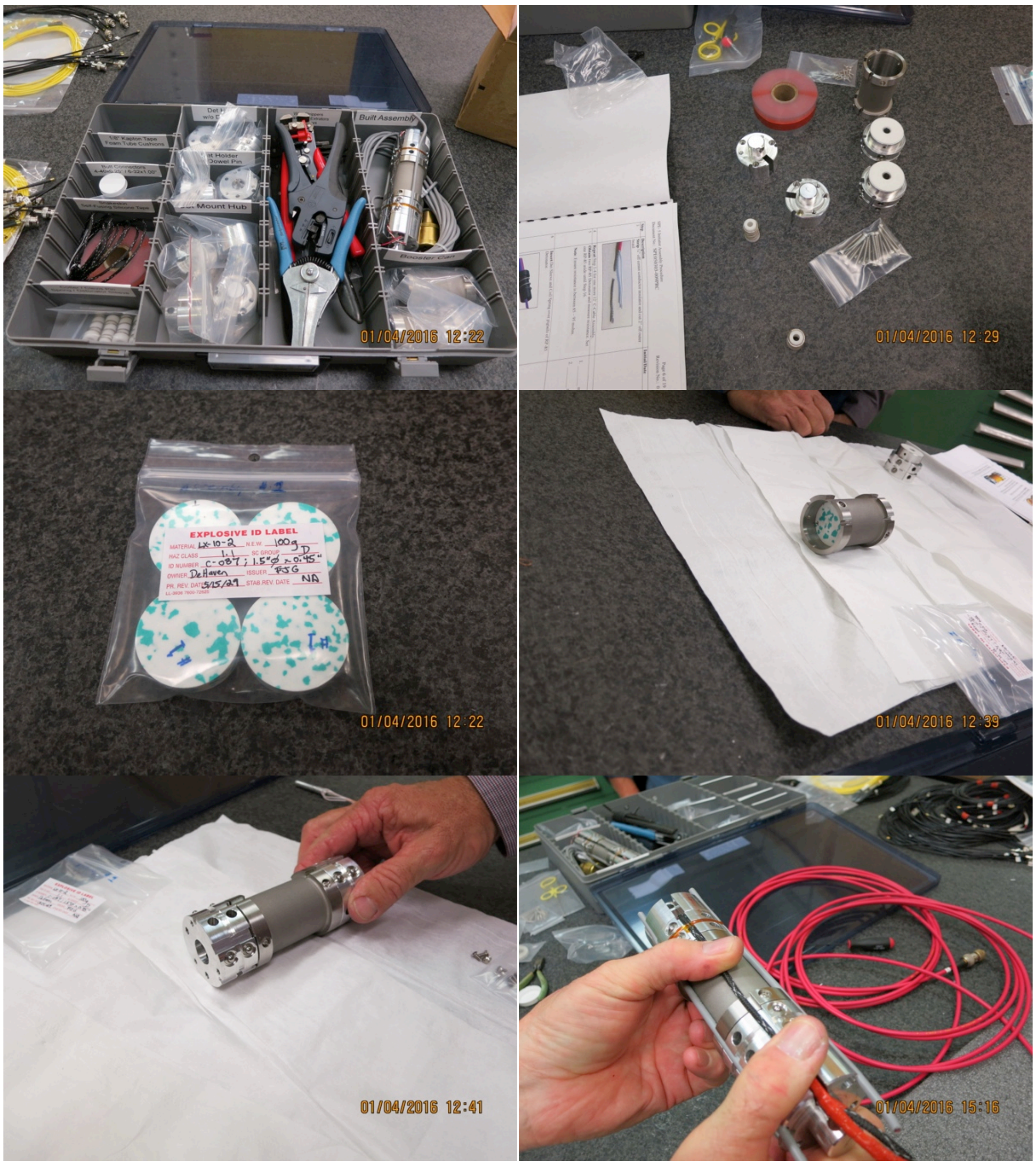


Figure 4. A series of photographs showing the booster assembly, including the booster parts kit (upper left), arrangement of the assembly parts (upper right), LX-10 booster pucks (center left), placement of the booster pucks inside the booster housing (center right), attachment of the booster ends (lower left), and attachment of the booster, pin and “water sensor dummy wire” connections (lower right).

Figure 5. A completed booster assembly ready to be inserted into the SPE5SS1 experiment.

As a result of the shipping logistics, assembly article 2 was shipped first and was therefore tested first as SPE5 sub-scale test 1 (SPE5SS1). Figure 6 shows the filled article before the assembly process and details the top pin configuration. The top pins were used on this sub-scale test to evaluate a pin diagnostic on the full-scale test. The piezoelectric pins were placed inside a "pin-plunger" assembly equipped with spring loading. To fully evaluate the response on the first test, 2 of the pins were placed flush against the PBXN-110 top surface, 2 of the pins were placed with about a 0.125 inch air gap between the PBXN-110 and the metal pin holder base, and 2 of the pins were positioned with an ~0.32 inch thick RTV section between the pin holder base and the PBXN-110 surface. As seen in Figure 6, each of the pin plunger units comes with a screw thread and spring for correct height adjustment before bolting the top cover in place.

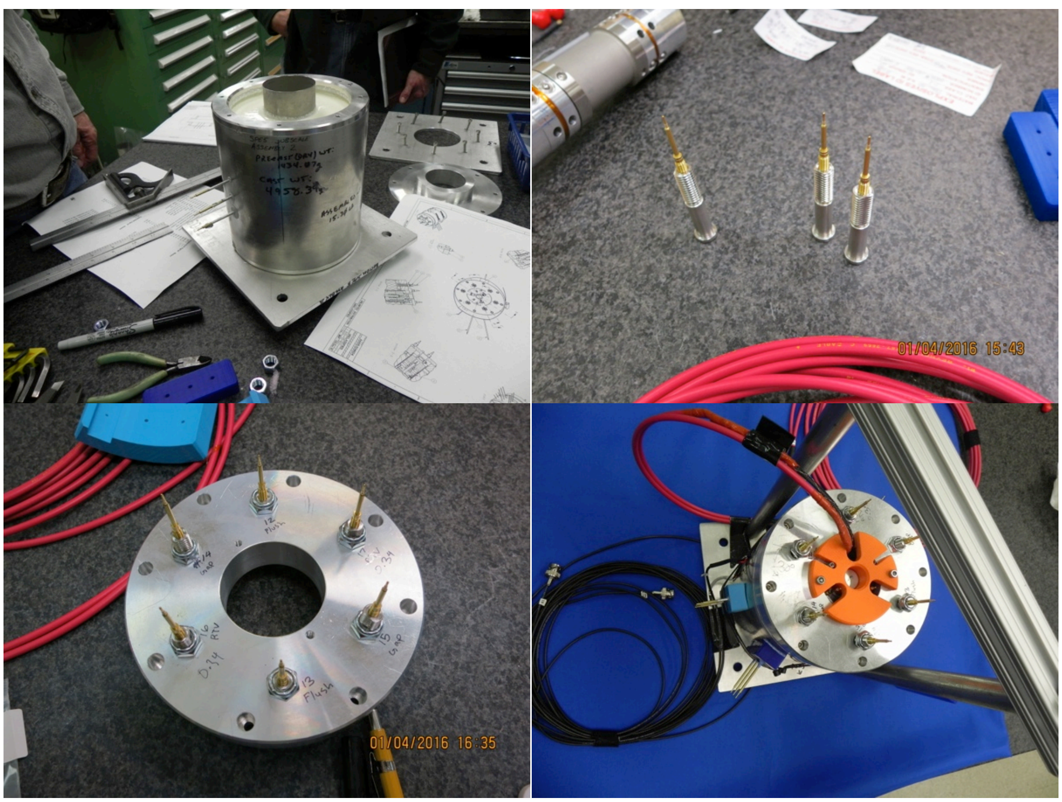


Figure 6. Photographs detailing the canister filled getting ready for final assembly (upper left), piezoelectric crystal pins in pin-plunger assembly (upper right), top plate assembly with pins installed (lower left), and completed assembly with booster inserted.

Figure 7 shows the test article after addition of the external pin blocks, piezoelectric pin pads, and PDV probes for the test. Once the assembly in the workroom and the initial firing tank checks (dry runs, etc.) were complete, the experiment was transported to the firing tank and placed on the shot stand within a shrapnel catcher as shown in Figure 8. Metal protection plates were put on top of the shrapnel catcher as show in Figure 9 which shows the before and after images of the test.

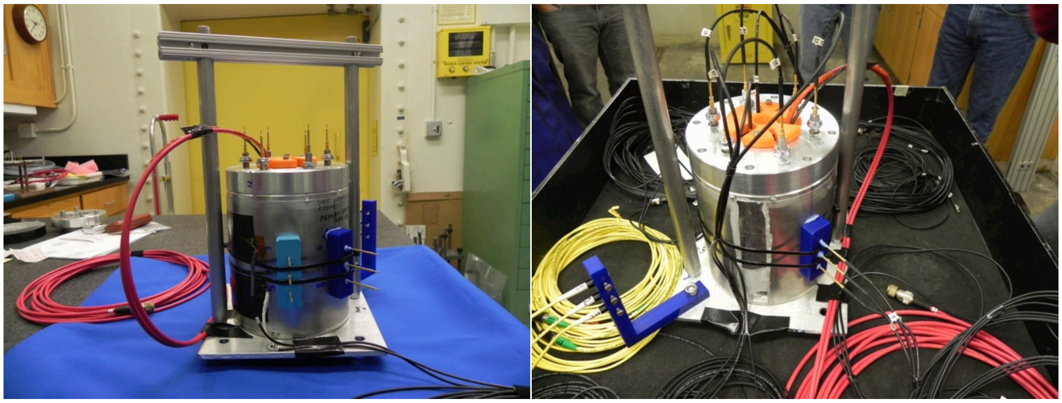


Figure 7. Final assembly photographs before transport to the firing tank. Note the pin block that holds the interior pins (light blue plastic), exterior pins on opposite sides (dark blue plastic on case), PDV probe bracket (dark blue plastic "L" bracket), and black tape covering 2 piezoelectric polymer pads for redundant case arrival timing.

Figure 8. Photographs of 2 different views of the experiment loaded on the shot stand inside the shrapnel catcher in the tank.

Figure 9. Photographs showing the before (left) and after (right) images as a result of firing the experiment in the 10 kg Spherical firing tank.

Figure 10 shows some close-up photographs of the damage on the top plate and shrapnel catcher. No significant tank damage was observed other than shearing of the bolts that held some of the protection plates on the top of the tank which was a clear sign of the shrapnel protection doing an adequate job during the test.

Figure 10. Detailed photographs showing the indentations in the top metal plate from throwing the top pins (left) and failure of the shrapnel catcher (right) during the experiment.

5. SPE5 Sub-Scale Test 2 (Article 1)

The 2nd SPE5 sub-scale test (SPE5SS2) using assembly article 1 was performed similarly to the first test, with a slight modification in the assembly for the top pins. In the first test, as will be described later in the Results Section, some of the top pin signal levels were low. It was also observed that a tag-along diagnostic in the form of a piezoelectric polymer pads taped to the outer case showed a high signal level, a result of the large surface area of the pad. During the assembly of the 2nd test, 4 of the top pins were replaced with the piezoelectric polymer pads, with 2 placed on ~0.32 inch thick RTV slabs and 2 placed on ~0.52 inch RTV slabs to bound the response expected in the full-scale SPE5 test.

Photographs of the shipped canister before assembly are shown in Figure 11. Figure 12 shows an up-close image of one of the piezoelectric polymer pads with Mylar tape around the leads for electrical insulation. A small film of vacuum grease was placed on the surface so it would make intimate contact with the surface and when used on the outer case (as seen in Figure 12) these were simply taped over with black tape in position.

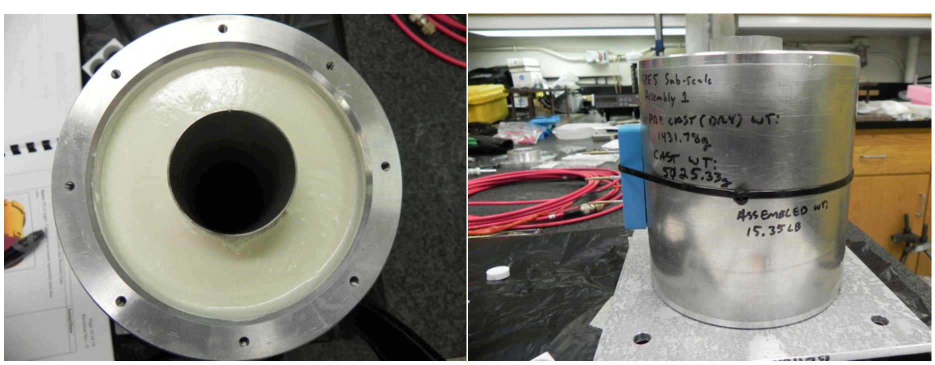


Figure 11. A top view of the explosive fill (left) and side view (right) before final assembly.

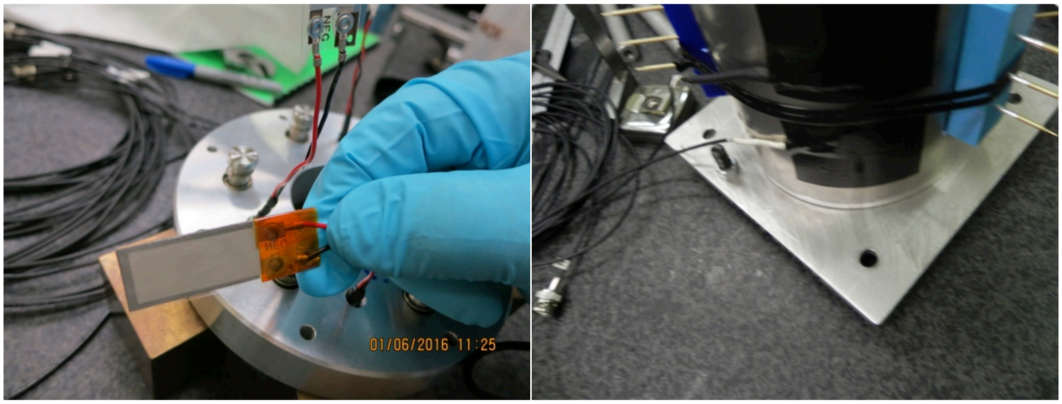


Figure 12. A close up photograph of the piezoelectric polymer pads with mylar tape around the riveted leads (left) and view of the piezoelectric pads taped on the outside of the assembly for case timing to compare with the piezoelectric crystal pins (right).

The assembly and positioning of the top plate with piezoelectric pins and pads is shown in Figure 13. The ~0.32 inch (2 each) and ~0.52 inch (2 each) RTV pads were placed on top of the PBXN-110 surface and the piezoelectric polymer pads were placed on the end of the metal pin plunger assemblies to tamp the back of the gauge. The other 2 pins were placed in contact with the PBXN-110 surface similar to the first experiment. The cover was carefully positioned on top of the assembly and tightened down before completing the assembly and booster insertion.

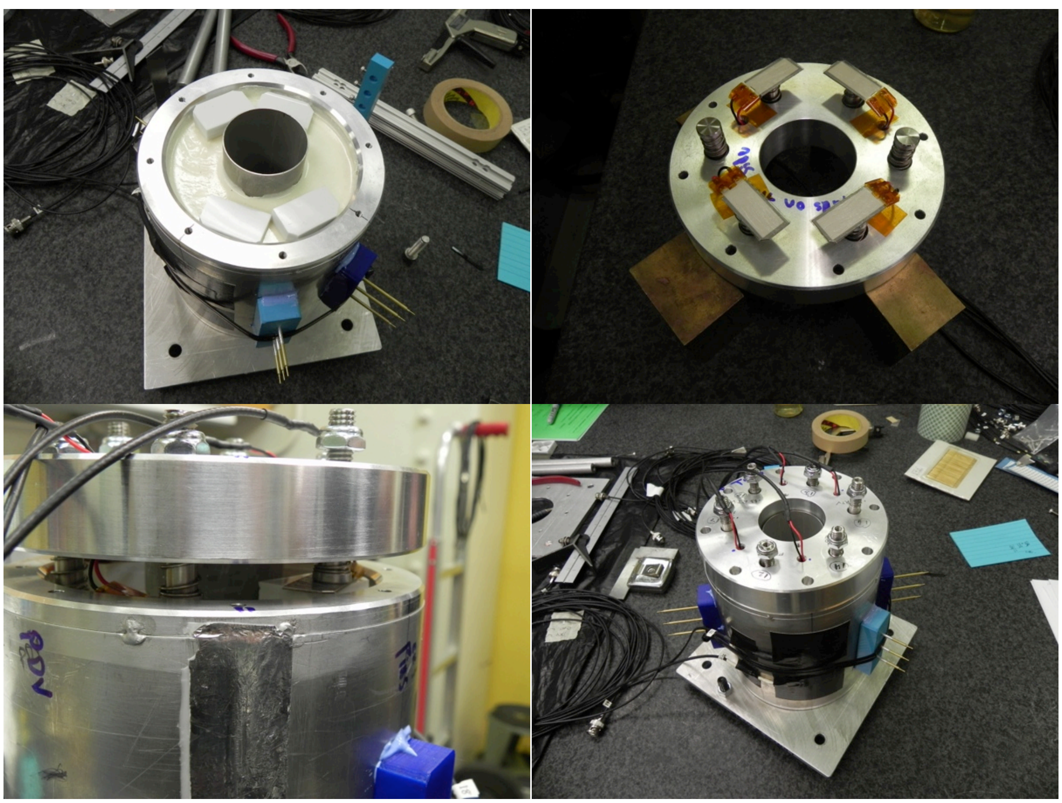


Figure 13. A view of the 2 different thicknesses of RTV pads (2 each) on top of the PBXN-110 explosive layer (upper left), close up photograph of the piezoelectric polymer pads in contact with the pin-plunger assemblies with pins removed (upper right), top cover being installed (lower left), and final assembly of the top cover showing the piezoelectric pad electrical leads coming out of the cover (lower right).

The completed assembled unit in the workroom is shown in Figure 14. After the assembly and the pre-test check in the tank were complete, the test article was transported to the test stand in the tank inside the shrapnel catcher for final diagnostic hook-ups and placing protection plates on top of the shrapnel catcher. Figure 16 shows the before-and-after images from the experiment.

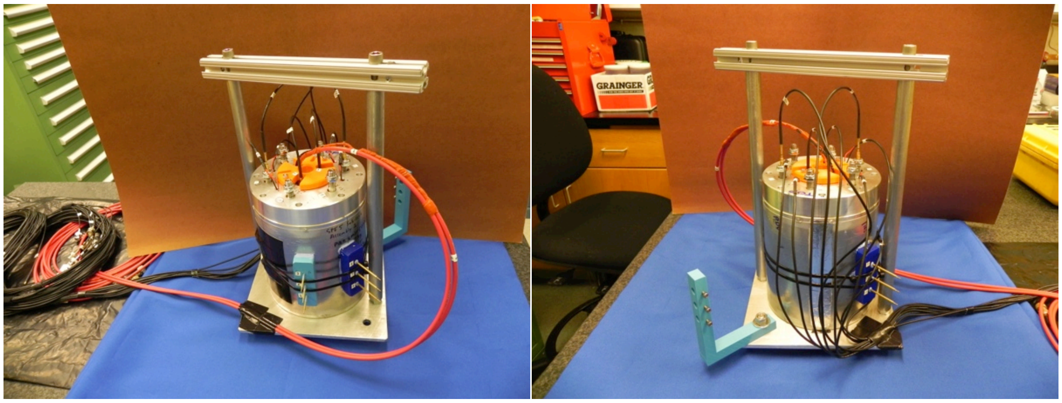


Figure 14. Final assembly photographs before transport to the firing tank. Note the pin block that holds the interior pins (light blue plastic), exterior pins on opposite sides (dark blue plastic on case), PDV probe bracket (light blue plastic "L" bracket), and black tape covering 2 piezoelectric polymer pads for redundant case arrival timing.

Figure 15. Photographs of 2 different views of the experiment loaded on the shot stand inside the shrapnel catcher in the tank.

Figure 16. Photographs showing the before (left) and after (right) images as a result of firing the experiment in the 10 kg Spherical firing tank.

6. Results and Discussion

The results and discussion for both experiments are included below. Each test is described first with highlights of the individual results followed by some general discussion comments comparing both experiments. Overall, the data and analysis was found to be straightforward without any anomalies in the results.

6.1 SPE5 Sub-Scale Test 1 (Article 2) Results

In the SPE5 sub-scale test 1, both of the detonators were functioned to test the booster under optimal conditions. Figure 17 displays the output of the Current Viewing Resistor (CVR) for both detonators. As seen by close overlap of the two voltage traces, the timing was as expected because both of the detonators were fired using the same capacitor discharge unit (CDU). Table 2 provides details from the piezoelectric pins and pads, including the position number, location, timing, and nominal signal level. The booster pins (1 and 2), internal and outer case pins (3-11), and outer case pads (18 and 19) all showed signal levels exceeding 40 volts. Only 1 of the top pins (13) flush with the surface of the PBXN-110 showed a reasonable signal level; the remaining pins (12 and 14-17) showed signal levels below 2 volts. The signal level below 2 volts is undesirable in the full-scale test due to the long cable lengths specific to the full-scale experiment. Based on low pin response and the response of the piezoelectric polymer pads exceeding 50 volts, it was desired to test the response of these pads during the 2nd test.

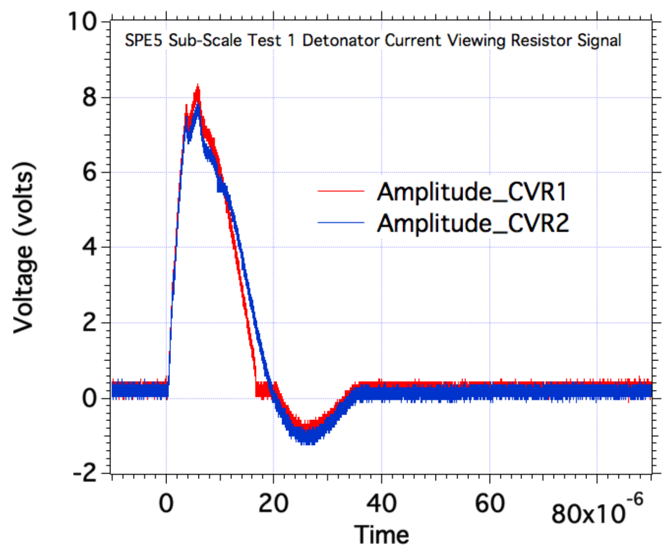


Figure 17. Current Viewing Resistor (CVR) for the detonator signals showing both detonators fired simultaneously with the same Capacitor Discharge Unit (CDU). Note the signal is attenuated 10x during the measurement.

Table 2. Summary of pin numbers, locations, timing, and nominal signal level for test SPE5SS1. Rotation angles are clockwise from a top view.

Pin	Location (angle clockwise rotation from internal pins)	Pin Timing (μs)	Signal Level
1	Booster Pin, top	10.4	60 V
2	Booster Pin, bottom	10.7	75 V
3	Internal, 0°, top	11.5	65 V
4	Internal, 0°, middle	11.7	40 V
5	Internal, 0°, bottom	11.4	65 V
6	External, ~135° rotated to internal, top	17.7	50 V
7	External, ~135° rotated to internal, middle	17.7	50 V
8	External, ~135° rotated to internal, bottom	17.6	40 V
9	External, ~315° rotated to internal, top	17.9	50 V
10	External, ~315° rotated to internal, middle	18.0	50 V
11	External, ~315° rotated to internal, bottom	17.9	50 V
12	Top, ~30°, flush	19.05	~1.5 V
13	Top, ~210°, flush	18.7	65 V
14	Top, ~330°, 0.125 inch air gap	18.6	~1.5 V
15	Top, ~150°, 0.125 inch air gap	18.3	~1.5 V
16	Top, ~270°, 0.32 inch RTV pad	18.5	~1.5 V
17	Top, ~90°, 0.32 inch RTV pad	19.45	~0.5 V
18	Piezo Pad, ~45°, top	17.9	>50 V
19	Piezo Pad, ~45°, bottom	17.8	>50 V

Table 3. Summary of calculated detonation velocity based on pin-pair Timing and a nominal 50 mm travel for test SPE5SS1.

Pin Pair	Transit Time (μs)	Velocity (km/s)
3 to 6	6.2	8.1
3 to 9	6.4	7.8
3 to 18	6.4	7.8
5 to 8	6.2	8.1
5 to 11	6.5	7.7
5 to 19	6.4	7.8

Table 3 provides calculations of the detonation velocity of the PBXN-110 material using 6 pin pairs from the internal and external piezoelectric pins using the nominal distance of 50 mm. As seen in table 3, the measured velocity ranges from 7.7 to 8.1 km/s, which is about 93 to 97% of the LLNL On-line Explosive Reference Guide number of 8.3 k/s. Given that only a nominal distance of 50 mm is used in this calculation and that the calculation assumes prompt detonation of the PBXN-110 material, this range of 93 to 97% of the detonation velocity appears more than acceptable as a confirmation of full detonation of the test article. It should be noted that in Table 3, the pin pairs at the top and bottom were used because both of the detonators functioned and the response around the center (up and down) of the charge was symmetric.

Figure 18 shows a graphical output of the internal and outer case pins as well as the booster and top pins. Comparing the internal and outer case pins, it can be seen that the internal pins were grouped as expected and the external pins were similarly grouped at a later time. Note that the center pins arrive later than the top and bottom pins as a result of the booster being initiated closer to the top and bottom pins than the center (up and down) of the charge. In looking at the booster and top pins outputs, it can be observed that some of these pin signals show a low response (<2 Volts). Figure 19 shows a magnified view revealing the signals below 2 Volts in amplitude.

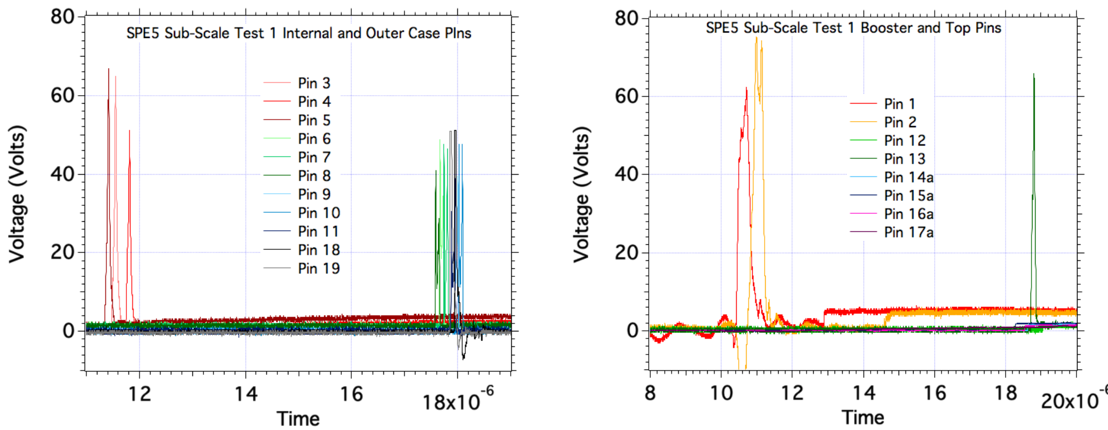


Figure 18. Pin output traces for the internal and outer case pins (left) and booster and top pins (right) in test SPE5SS1.

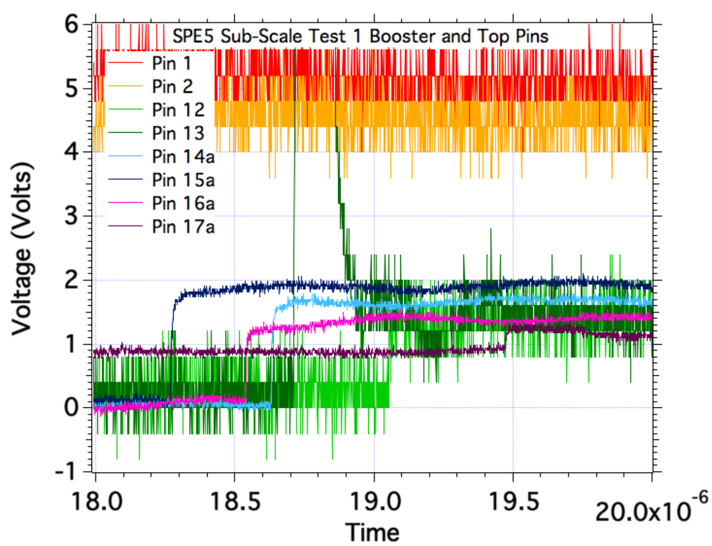


Figure 19. Magnified view of the pin traces for the pins in the top cover showing the low magnitude signals in test SPE5SS1.

Figure 20 shows the PDV probe response of test SPE5SS1. As seen in the plot, the top and bottom probes are similar in timing and magnitude with the center probe slightly later in time and higher in magnitude as a result of the slight “mach stem” that forms from the colliding shock waves of the initiation of both the top and bottom detonators. A 2 pulse signal is also seen. The first shock wave leaving the booster and initiating the PBXN-110 creates the first pulse, while a reflected shock caused by the implosion of the booster tube likely creates the second. This second pulse is formed when the shock wave reaches the central axis of the test article and reflects back toward the outer surface.

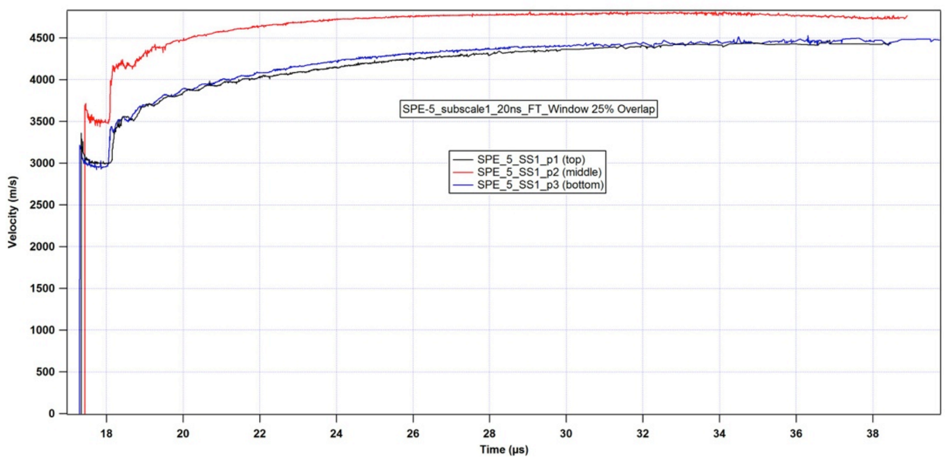


Figure 20. PDV traces for the PDV probes in test SPE5SS1.

6.2 SPE5 Sub-Scale Test 2 (Article 1) Results

In the SPE5 sub-scale test 2, only the bottom detonator was functioned to test the viability booster design under sub-optimal conditions. Figure 17 displays the output of the Current Viewing Resistor (CVR) for both detonators. As seen by the traces, only the first detonator is fired and the 2nd detonator CVR signal remains on the baseline. Table 4 provides details from the piezoelectric pins and pads, including the position number, location, timing, and nominal signal level. The booster pins (1 and 2), internal and outer case pins (3-11), and outer case pads (18 and 19) all showed signal levels exceeding 35 volts. Note that some of the signals were slightly different from the first test because only the bottom detonator was functioned and the shock wave was less normal to the directional crystal surface of the pin. The piezoelectric pins and pads in the top cover showed improved signal magnitude with only 2 of the signals on the order of ~5 Volts. The remainder of the signals were at 50 Volts or greater. Based on this result, the piezoelectric polymer pads provide a better response than piezoelectric crystal pins in the top plate.

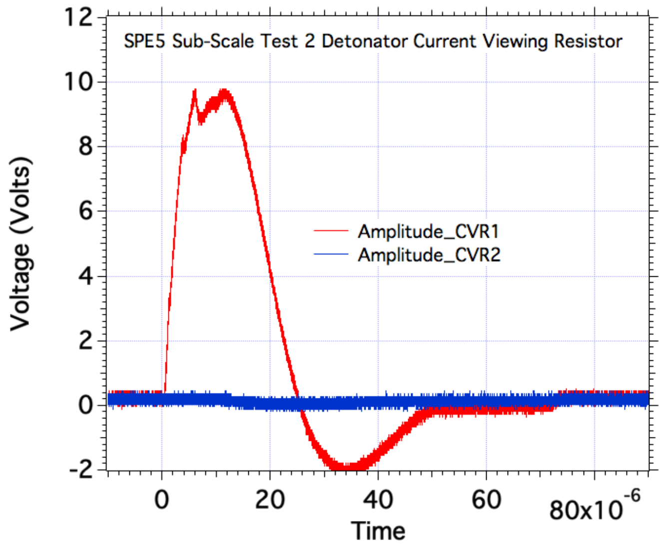


Figure 21. Current Viewing Resistor (CVR) for the detonator signals showing both detonators fired simultaneously with the same Capacitor Discharge Unit (CDU). Note the signal is attenuated 10x during the measurement.

Table 4. Summary of pin numbers, locations, timing, and nominal signal level for test SPE5SS2. Rotation angles are clockwise from a top view.

Pin	Location (angle clockwise rotation from internal pins)	Pin Timing (µs)	Signal Level
1	Booster Pin, top	14.1	>90 V
2	Booster Pin, bottom	14.1	>90 V
3	Internal, 0°, top	14.2	50 V
4	Internal, 0°, middle	12.3	50 V
5	Internal, 0°, bottom	11.3	50 V
6	External, ~135° rotated to internal, top	18.7	35 V
7	External, ~135° rotated to internal, middle	17.9	35 V
8	External, ~135° rotated to internal, bottom	17.7	35 V
9	External, ~315° rotated to internal, top	18.8	35 V
10	External, ~315° rotated to internal, middle	18.1	30 V
11	External, ~315° rotated to internal, bottom	18.0	30 V
12	Top, ~70°, flush	22.0	70 V
13	Top, ~250°, flush	21.6	50 V
14	Top, ~20°, 0.32 inch RTV pad	22.1	>200 V
15	Top, ~200°, 0.32 inch RTV Pad	22.1	>200 V
16	Top, ~340°, 0.52 inch RTV pad	22.4	55 V
17	Top, ~160°, 0.52 inch RTV pad	22.7	~5 V
18	Piezo Pad, ~45°, top	18.9	100 V
19	Piezo Pad, ~45°, bottom	17.8	80 V

Table 5. Summary of calculated detonation velocity based on pin-pair Timing and a nominal 50 mm travel for test SPE5SS2.

Pin Pair	Transit Time (µs)	Velocity (km/s)
5 to 8	6.4	7.8
5 to 11	6.7	7.5
5 to 19	6.5	7.7

Table 5 provides calculations of the detonation velocity of the PBXN-110 material using 3 pin pairs from the internal and external piezoelectric pins using the nominal distance of 50 mm. Because only the bottom detonator was functioned, only the bottom pin pairs were used since the timing from the top pin pairs resulted in unrealistic numbers that exceed the known detonation velocity, based on the geometric effects. As seen in table 3, the measured velocity ranges from 7.5 to 7.8 km/s, which is about 90 to 94% of the LLNL On-line Explosive Reference Guide number of 8.3 k/s. Given that only a nominal distance of 50 mm is used in this calculation and that the calculation assumes prompt detonation of the PBXN-110 material, this range of 90 to 94% of the detonation velocity appears acceptable, albeit on the low side, as confirmation of full detonation of the test article. It should be noted that with only the bottom detonator functioning some of the geometric effects can also contribute to the slightly lower value, because the detonation will first be directed upward and cause a slight delay in initiating the material as the detonation travels toward the bottom set of pins.

Figure 22 shows a graphical output of the internal and outer case pins as well as the booster and top pins. In comparing the internal and outer case pins, it can be seen that the internal pins traveled from bottom to top as expected, with only the bottom detonator firing and the external pins reported similarly. In looking at the booster and top pins and comparing these data to the results shown in Figure 19, it can be observed that the amplitude response of the piezoelectric pads is an improvement over the response of the piezoelectric crystal pins used in the first test.

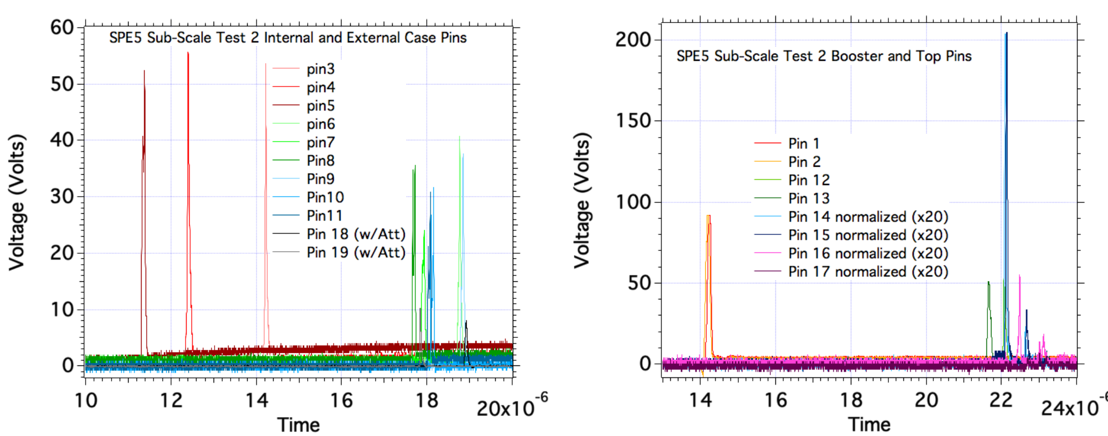


Figure 22. Pin output traces for the internal and outer case pins (left) and booster and top pins (right) in test SPE5SS2.

Figure 23 shows a magnified view of the signals with pins 14 and 15 (with ~0.32 inch RTV pad) off scale (over 200 Volt peak as seen in Figure 22), pins 12 and 13 (flush to surface) and pad 16 (~0.52 inch RTV pad) showing about a 50 Volt signal, and Pin 17 (~0.52 inch RTV pad) shows a low, ~5 Volt, response for an unknown reason. Given the "on-the-fly" addition of the piezoelectric pads on the 2nd test, it seems possible that one of the cable connections or solder joints could have been damaged or may have been in intimate contact, leading to the low response.

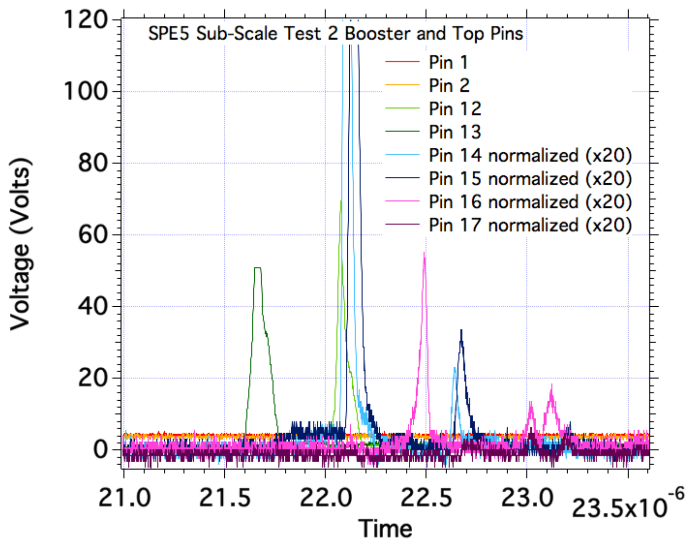


Figure 23. Magnified view of the pin traces for the pins in the top cover showing the low magnitude signals in test SPE5SS2.

Figure 24 shows the PDV probe response of test SPE5SS2. As seen in the plot, as a result of only the bottom detonator firing, the bottom probe reports first, followed by the middle and top probes. A 2 pulse signal is seen, similar to the first test, and is likely due to the first shock wave leaving the booster to initiate the PBXN-110, followed by an implosion of the booster tube resulting in a reflected shock from when the shock wave reaches the central axis and reflects back toward the outer surface.

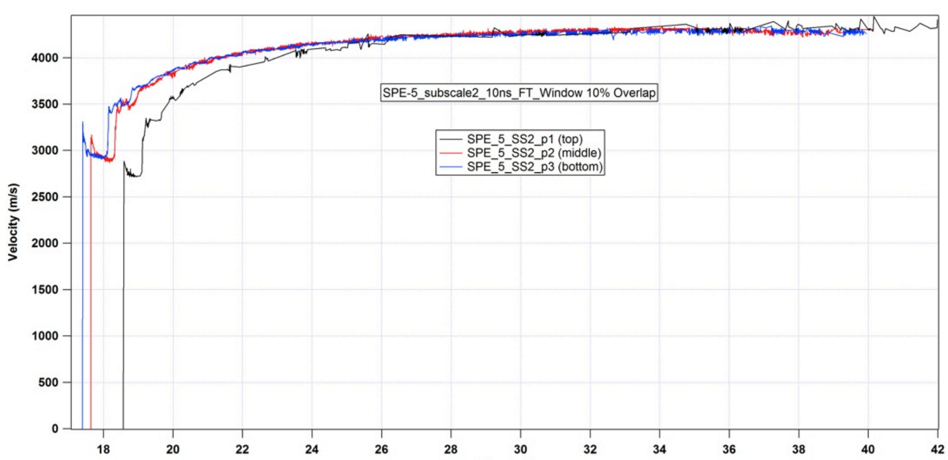


Figure 24. PDV traces for the PDV probes in test SPE5SS2.

6.3 Overall Discussion

In comparing the results of the 2 experiments, both articles functioned and detonated as designed. The pin and PDV diagnostics measured the expected trends whether both or a single detonator within the booster was detonated at the start of the event.

Conclusions

A series of 2 SPE5 sub-scale tests were performed to experimentally confirm that a booster system designed and evaluated in prior tests would properly initiate the PBXN-110 case charge fill. Different piezoelectric pin and pad configurations were utilized in the top plate assembly to evaluate diagnostics in advance of the full-scale test. To further quantify the margin of the booster operation, the 1st test (SPE5SS1) was functioned with both detonators and the 2nd test (SPE5SS2) was functioned with only 1 detonator. A full detonation of the material was observed in both experiments as measured by the pin timing and PDV signals. The piezoelectric pads were found to provide a greater measured signal magnitude during the testing with an RTV layer present, and the improved response is due to the larger measurement surface area of the pad.

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